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ABSTRACT

A study attempted to determine whether force and duration parameters are programmed in an interactive or independent fashion prior to executing ballistic type isometric contractions of graded intensities. Four adult females each performed 360 trials of producing ballistic type forces representing 25, 40, 55, and 75 percent of their maximal voluntary isometric elbow flexor strength over five test days. During observation of the tests, duration of peak force and average rate at which force was produced were monitored and recorded. The data suggested that rate of force development and duration of force development varied inversely from trial to trial within different targeted force conditions. Furthermore, partial correlational analysis demonstrated that this relationship was independent of feedback from previous trials. It was concluded that some type of internal computation to adjust time and force parameters for one another takes place during the latency period occurring between when a subject decides to initiate a response and when the actual overt force is manifested. (Author/CB)

Interaction of Rate of Force Development and Duration of Rate in Isometric Force Reproduction[1]

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Running Head: Reproduction of Isometric Force

Summary.-The purpose of this study was to determine whether force and duration parameters are programmed in an interactive or independent fashion prior to executing ballistic type isometric contractions of graded intensities. The data suggested that rate of force development and duration of force development varied inversely from trial to trial within different targeted force conditions. Furthermore, partial correlational analysis demonstrated that this relationship was independent of feedback from the previous trial. Consequently, it was inferred that some type of internal computation to adjust time and force parameters for one another takes place during the latency period occurring between when a subject decides to initiate a response and when the actual overt force is manifested.

The notion of the motor program has been hypothesized to account for the control of responses which occur too rapidly for higher level information processing mechanisms to regulate their course because of peripheral error feedback (Schmidt, 1976). For the most part, it is currently believed that such programs are generalized central structures which can organize, initiate and control a variety of movement patterns, such as walking, throwing and jumping (Schmidt, 1982). The basic idea is that prior to the initiation of such a response an appropriate program representing a particular movement pattern is selected (e. g., the overhand throwing motion) and a variety of "best guess" movement parameters input into it. For instance, whether to throw long or short, jump high or low, or walk fast or slow is believed to be mediated by inputing different values for force and duration into the generalized program for each type of response (Schmidt, 1975). While the generalized program is believed to contain certain invariant features such as necessary movement components, their order of initiation, and their relative temporal structuring (Summers, 1977), other variable parameters such as force and force duration are believed to control movement gain.

Clearly, to produce precise forces in the absence of higher level closed-loop feedback control processes, programmed force-time parameters must be exact. Too short a duration with a constant force parameter will cause a response to fall short, and too great a force parameter for a fixed duration will yield a response of greater than desired magnitude. How individuals select these two parameters during ballistic responses is the subject of the present investigation. Are they selected independently during programming, prior to response initiation, and through trial and error over a series of trials an optimal combination discovered and thereafter reproduced? Or is there a complex interaction between force and time variables during programming that adjusts these motor program inputs for one another so that from trial to trial they may vary, but their product will

approximate a desired magnitude?

While the former alternative may exist, it would seem that it would be less efficient than the latter since it would require storing a larger amount of force and time information. This would include retaining force and duration values for producing precise force magnitudes when limbs start at different positions, contain different masses, and experience different degrees of fatigue. Indeed, Schmidt (1982) has questioned whether enough storage capacity is available in the nervous system for motor programs to operate in such a fashion.

On the other hand, the latter alternative would seem a bit more elegant in that it infers a more active decision mechanism which evalutes specific situations, decides on appropriate response magnitudes, and computes estimates for required force and duration parameters. As suggested, the selection and modification of these parameters would be performed interactively prior to response initiation, based on intended output information. The existence of such a process would seem consistent with recent neurophysiological evidence for internal feedback loops in the nervous system that appear to become activated prior to overt actions (Kelso, & Stelmach, 1976). Behavioral evidence for amending tracking errors without visual feedback (Angel, Garland, & Fischler, 1971) also is suggestive of a central mechanism which monitors and controls voluntary movements before they are manifested overtly.

Seemingly, these two programming strategies could be studied behaviorally by having individuals attempt to produce target forces of a specified magnitude at a maximum rate and then correlating force and time parameters within subjects over trials. If force and time information is processed and programmed jointly prior to response initiation, an inverse correlation would be anticipated since longer durations would have to be compensated by smaller forces and <u>vice versa</u>. Furthermore, the possibility that such a relationship might be a function of feedback from the

previous trial rather than preresponse processing might be controlled by partialing out force and time variance from the preceding trial from any force and time relationship that may be manifested. In essence this strategy would be equivalent to correlating force and time measures across trials whose immediately preceding force and time values were constant.

Method

Four female volunteers ranging in age from 19-25 each performed 360 trials of producing ballistic type forces representing 25%, 40%, 55% and 75% (72 trials per condition) of their maximal voluntary isometric elbow flexor strength (105° against the force arm of a Cybex II) over five test days. During each session subjects sat in front of a computer screen on which they viewed a horizontal line representing the target force they were attempting to produce. Subsequently a preparatory auditory signal occurred to indicate that a trial had begun. Upon viewing a line moving from left to right on the screen, appearing at a random time interval of between 1 and 4-sec. after the preparatory signal, subjects were instructed to exert force in one burst as quickly as possible and make the peak of the force curve coincide with the target line. Additionally, instructions urged subjects to try and make no corrective actions during a response.

Force blocks (18 trials per block) were presented in a random order from session to session, and were separated by a four minute rest interval. Trials within blocks were separated by ten seconds. Data points were collected by computer at the rate of one per msec. and stored for subsequent analyses on floppy disks. The actual scores of interest were the (a) duration to peak force and (b) average rate at which force was produced (peak force/ force duration).[2]

Results and Discussion

Session 1 was utilized only to familiarize subjects with the task and apparatus. Thus, these data were not included in the analysis. The first three trials in each condition during Session 2 to Session 5 were also considered practice/adjustment trials and were similarly deleted from subsequent analyses.

As seen in Table 1, rates at which forces were produced increased with the percent of maximum at which subjects were asked to work ($F_{3,9} = 121.35$, $p < .001$). Sheffé tests showed rates across conditions to differ from one another ($p < .01$). This in itself was an interesting finding in that across conditions subjects were urged to respond with maximal speed. Theoretically, the simplest strategy for subjects would seem to be to create force at their maximal rate (as seen in the 70% condition) and adjust durations accordingly, since this would only require altering one variable, duration. However, it appeared that they were unable to operate in such a fashion. Most probably this phenomenon is a consequence of the direct relationship that exits between force requirements and motor unit recruitment, derecruitment and rate coding (DeLuca, LeFever, McCue, & Xenakis, 1982). As suggested by DeLuca et al. (1982), rate coding is related to fine force adjustments while recruitment/derecruitment provides grosser force increments. It would seem that for subjects to maintain similar rates of force production across conditions a strategy predominantly employing rate coding would be essential. Here, within limits of the frequency range of recruited motor units, peak force could be adjusted by increasing or decreasing motor unit firing rate while concomitantly adjusting contraction duration to reach a particular target force. Possibly, the utilization of such a mechanism might have allowed a constant rate of force development across conditions had subjects been urged to meet such a rate rather than time criterion. However, to attain ballistic type forces, as required in the present study, motor units

could only fire once or twice during a contraction, making frequency adjustments impossible, leaving recruitment as the predominant mechanism for varying force (Milner-Brown, Stein, & Yemm, 1973). This would mean that for the 25% contractions a proportion of the lower threshold motor units were recruited and derecruited over the brief force interval. For the 40%, 55%, and 70% contractions it is probably the case that motor units having higher thresholds were progressively recruited, increasing overall force, as well as rate of contraction. Operating with such a synchronous control mechanism would very likely restrict the rates at which force could be developed in each condition if targeted forces were to be approximated in a ballistic fashion.

Insert Table 1 about here

Response durations reflected a similar pattern to rate of force development ($F_{3, 9} = 103.67$, $p < .01$). Sheffé tests showed times to peak force across conditions to differ from one another ($p < .05$). These durations were expectedly short, and in the range of responses typically thought of as under open-loop control (Carlton, 1981), i.e., too short in duration for visual feedback from the computer screen to be utilized by higher level information processing mechanisms to adjust forces. Thus the rate at which force was developed as well as the duration to peak force could reasonably be assumed to be programmed.

To determine the degree of force-duration interdependence during programming, which was independent of force and time values for the immediately preceding trial, second order partial correlations were run within subjects and conditions between average rate with which force was

developed and duration. Significant inverse coefficients ($p < .01$) were found for all but one individual in the 25% condition. Across subjects coefficients averaged -.36, -.53, -.59, and -.76 for the 25%, 40%, 50%, and 70% conditions (see Table 1).

As suggested, these data provide evidence in support of the notion that force and time parameters in the motor program are selected in an interdependent way such that a high rate of force production will be associated with a short duration and vice versa. Furthermore, it appears that this computation occurs independent of the prior response's feedback and during the latency period between when the subject decides to initiate a response and the actual overt manifestation of force.

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Footnotes

[1]Reprints available from D. Siegel, Department of Exercise and Sport Studies, Smith College, Northampton, MA 01063.

[2]Pilot data demonstrated that peak force for such responses was a perfect linear function of these two variables. It appears that prior to a response subjects decide on a rate at which force will be developed and a duration over which this rate will continue.

Table 1

Force and Time Parameters across Conditions

	25%	40%	55%	70%
Rate of Force Development (N·m/msec.)	.15 (.02)	.19 (.03)	.22 (.03)	.26 (.03)
Time to Peak (msec.)	79 (11)	96 (14)	111 (15)	120 (13)
Constant Error Maximum Force (N·m)	.79 (.34)	.52 (.34)	.43 (.35)	-.20 (.62)
Variable Error Maximum Force (N·m)	1.76 (.13)	1.68 (.18)	1.74 (.16)	1.58 (.30)
r rate with time (partial)	-.36 (.13)	-.53 (.10)	-.59 (.05)	-.76 (.07)